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THE EFFECT OF INITIAL DATA UNCERTAINTIES ON THE PERFORMANCE

OF STATISTICAL TROPICAL CYCLONE PREDICTION MODELS

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ABSTRACT

Statistical prediction models in operational use at the National Hurricane Center have a potentially high degree of forecast skill on condition that these models are supplied with precise information on current and previous storm position and storm motion. In an operational environment there are inherent uncertainties involved in the determination of these parameters with the result that the performance of the models is compromised.

Over the five year period 1968 through 1972, the average error between the operational specification of initial storm position and that determined by a post-season analysis (positioning error) was about 27 nmi while the initial motion error was about 3.5 knots. This paper examines the specific impact of these data uncertainties on the performance of certain statistical models and makes recommendations concerning modifications to the models to make their data requirements commensurate with the current ability to provide such data.

I. INTRODUCTION

The National Hurricane Center (NHC) uses the output from a number of prediction models as objective guidance preparatory to the issuance of tropical cyclone advisories. A brief description of those techniques which have been in operational use at NHC over the past several hurricane seasons is given in Table I. Each of these systems is completely

1. NHC67 (Miller, Hill, Chase, 1968)---Stepwise screening regression model using predictors derived from current and 24-hour old 1000, 700, and 500-mb data. Also uses persistence in the early forecast periods.
2. SANBAR (Sanders and Burpee, 1968)----A filtered barotropic model using input derived from the 1000 to 100-mb pressure-weighted winds. Requires the use of "bogus" data in data-void areas. System modified by Pike (1972) so that the wind field near the storm conforms to current storm motion.
3. HURRAN (Hope and Neumann, 1970)----An analog system using a data base of 703 storms dating back to the year 1886.
4. CLIPER (Neumann, 1972)----Stepwise multiple screening regression system using predictors derived from climatology and persistence.
5. NHC72 (Neumann, Hope, Miller, 1972)----A modified stepwise multiple screening regression system which combines NHC67 and CLIPER into a single model.
6. NHC73 (Neumann, Lawrence, 1973)----Similar in concept to NHC72 except uses the so called "perfect-prog" method to introduce numerical prognostic data into the prediction scheme.
7. MOHATT (Renard, et al, 1973)----The Navy's modified HATRACK scheme which uses a geostrophic steering concept applied to heavily smoothed analyses and prognoses produced by the Fleet Numerical Weather Central, Monterey, Calif. A "bias" correction is applied to the forecast after observing initial 12-hour performance.

Table 1. Tropical cyclone prediction models available to NHC on a routine operational basis.

computerized and requires the specification of one or more parameters
involving storm position and storm motion as partial data input each
time the program is run. To varying degrees, uncertainties in the
operational specification of these parameters compromise the performance
of the systems. The purpose of this paper is to examine these uncer-
tainties, to determine their effect on the performance of several of
the current statistical models and finally, to make recommendations con-
cerning possible modifications to current statistical models so as to
make their data requirements commensurate with the current "state-of-
the-art" of estimating storm position and storm motion in an operational
environment.

2. RELATIVE IMPORTANCE OF VARIOUS STATISTICAL PREDICTORS

The ability of statistical tropical cyclone displacement models to
achieve forecast skill, often referred to as reduction of variance, is
derived from predictors systematically selected either from climatology,
persistence or some type of environmental data which imply a synoptic
steering environment. The method by which these three predictor classes
are utilized by the NHC72 prediction model is illustrated in Fig. 1. The
final NHC72 forecast is a composite of two subsystems, identified in
Fig. 1 as a CLIPER (acronym for climatology and persistence, Neumann,
1972) forecast and a synoptic forecast. Appropriate weighting factors
are applied to the subsystem forecasts to arrive at a final NHC72 fore-
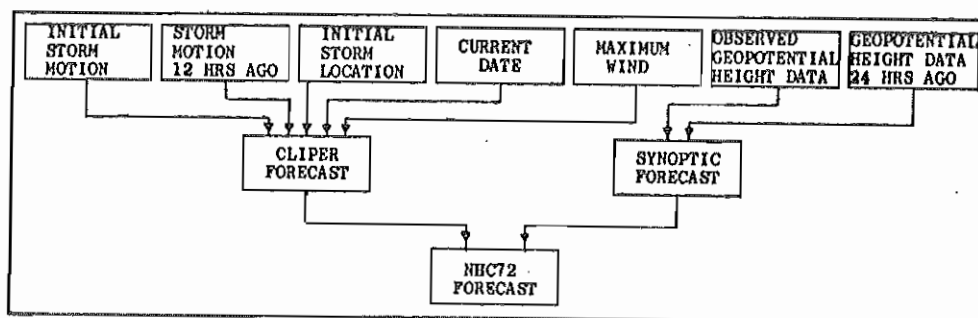cast.

Fig. 1. Algorithm for the NHC72 prediction model (From Neumann, et al,
         1972)

These weighting factors are both time and space dependent. Regardless
of the area under consideration, the short range forecast produced by
any statistical model is weighted more heavily toward persistence
(initial or past storm motion) than it is to climatology (storm posi-
tion) or to synoptic data. When one considers that current storm motion

represents the integrated effect of the synoptic steering environment on the storm, it is not surprising that persistence yields more fore- casting skill than does the synoptic data itself.

The reduction of variance realized from persistence depends to a certain degree on the manner in which a given model treats these data. It can be noted from Fig. I, for example, that the NHC72 model requires very explicit information on storm motion. Other models in use at NHC treat persistence in a more implicit manner. There are generally three ways in which persistence can be injected into a prediction system. The simpliest technique is to use the current and 12-hour old position of a storm as a measure of current motion. Another method uses addition- ally, the 24-hour old position. The advantage of the latter is that more information on changes in curvature and accelerations is pro- vided. In both of these methods, the speed and direction is, in effect, averaged over a 12 hour period.

The third method (used in the CLIPER subsystem of Fig. I) requires the instantaneous specification of current and 12-hour motion. It is, of course, impossible to specify initial motion to the same degree of accuracy as that implied by the "best-track" since such a specification implies a knowledge of the future position of the storm. Nevertheless, by careful analysis of the available data including the average motion over the past 12 and 24 hours, the forecaster is generally able to sup- ply better information on current motion than that which is implied solely from previous 12 hourly storm positions. Based on 1973 and 1974 operational data, for example, initial motion derived by fitting a second-order polynomial to the current, 12-hour old and the 24-hour old positions was in error an average of 3.9 knots whereas the error using the instantaneous motion supplied by the forecaster was 3.0 knots, a thirty percent error reduction. These errors were computed by vectorial subtraction from the "best-track"[1] initial motion vector. Thus the fore- caster has the ability to inject additional information into a statistical prediction system which otherwise would not be available.

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[1]The accepted storm track after a careful post-analysis.

Fig. 2 shows, for the NHC72 development data set, the relative impor-
tance of this type of explicit persistence compared with the other two
classes of predictive information, that is, climatology and synoptic
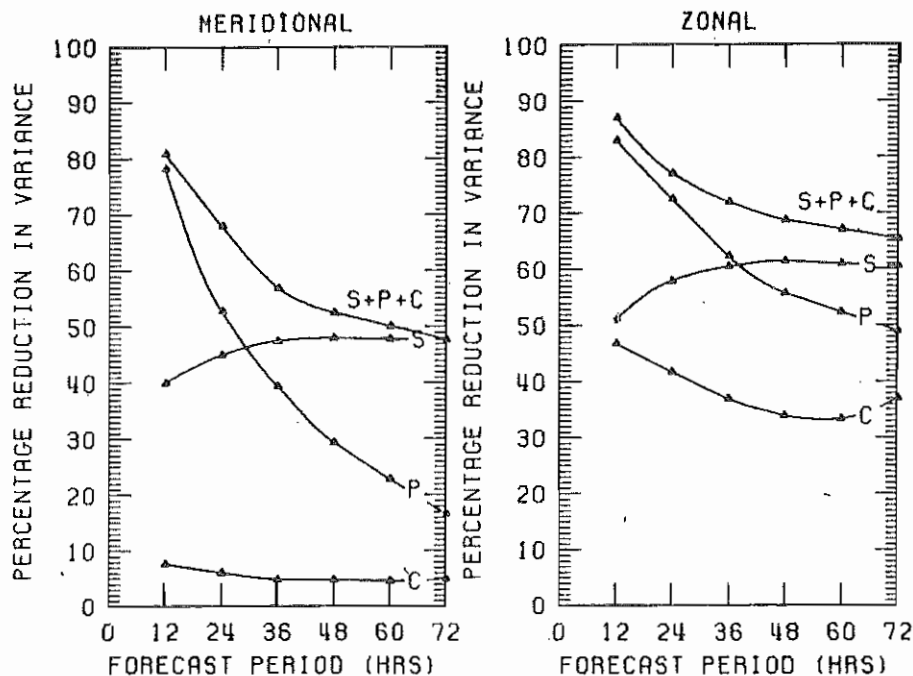data.

Fig. 2.   Reduction of variance provided by predictors derived from
           persistence (P), climatology (C) and synoptic data (S),
           based on the developmental data for the NHC72 prediction
           model.   The cumulative reduction of variance is given by
           curve labeled S+P+C.

The reduction of variance potential of persistence in the early fore-
cast periods for both zonal and meridional motion is clearly evident.
Synoptic data, a relatively poor predictor in the early forecast
periods, takes on increased significance in the latter half of the
forecast period.   It is also seen that climatology, by itself, is a
poor predictor throughout the forecast period and is practically worth-
less in reducing the variance of meridional storm motion.   That is to
say, knowing only the storm position, one can do nothing more than pre-
dict a constant northerly component of storm motion which, for Atlantic
storms, averages a little over 5 knots.

Additional details on the reduction of variance potential for the
various predictors over different geographical sections of the
Atlantic tropical cyclone belt is given by Neumann and Hope (1973).

The authors point out, for example, that persistence is twice as effective in reducing the variance of tropical cyclone motion before storm recurvature into the westerlies as it is after recurvature.

3. BEST-TRACK VS. OPERATIONAL INPUT DATA

In the previous section it was shown that, insofar as development data are concerned, persistence is principally responsible for the reduction of variance of tropical cyclone motion for the early portion of the forecast period. In developing a statistical prediction system it is usually convenient to use persistence information as derived from the best-track. For a number of reasons, it is not possible in an operational environment to determine storm position and storm motion with the same precision as that implied by the best-track. The forecaster simply utilizes the latest and what he considers at that time to be the most reliable information available.

The statistical models are thus operationally initialized with storm position and storm motion containing an error component not included in the original data set from which the prediction equations were developed. This causes an over-weighting of climatology and persistence by the prediction equations. One seemingly obvious solution would be to use operational data in lieu of best-track data in the development data. However, the short period of record of the operational data compared to the best-track data precludes such a direct approach. The problem is analogous to using Model Output Statistics (MOS) data in lieu of "perfect-prog" data in other statistical prediction systems (See Klein and Glahn, 1974).

A study of initial position and initial motion errors was made for the five-year period 1968 through 1972. Positioning error is defined as the vector difference between the position supplied to the objective systems and the corrected position as determined from the post analysis best-track. Similarly, the initial motion error is defined as the vector difference between the instantaneous motion supplied by the forecaster to the objective systems and that determined from the best-track. All available data were used in the analysis, giving a total of 465 cases over the five year period.

    a. Initial position errors. A plot of the 465 initial position errors is shown in Fig. 3. For purposes beyond the scope of this study, the data have been fitted to a bivariate normal distribution. Although no further use of these computed sample parameters is made in this study, it should be pointed out that without suitable transformations, the theoretical distribution does not adequately describe the observed density distribution.
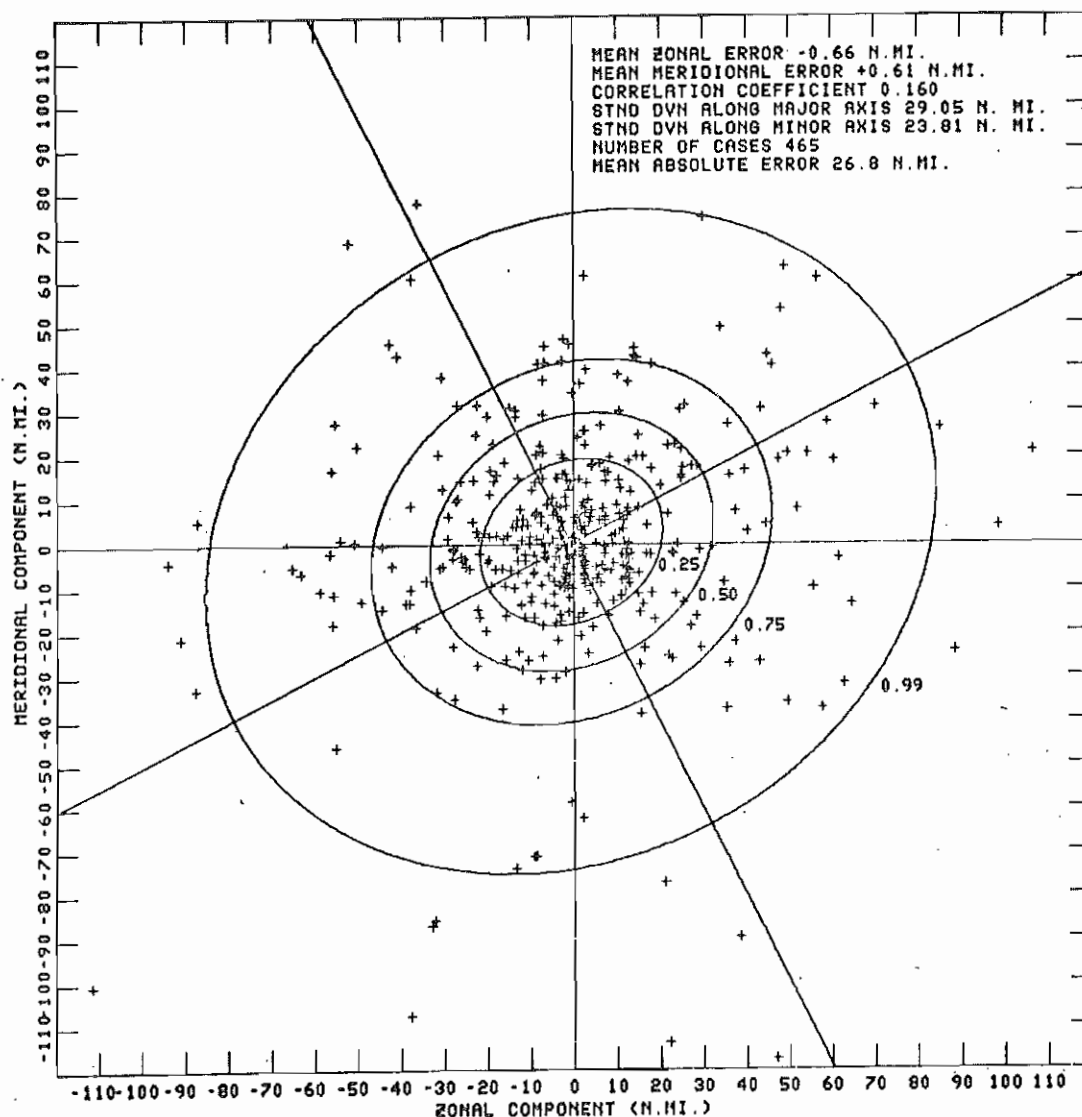
Fig. 3. Tropical cyclone positioning errors 1968 through 1972. The
(X,Y) origin represents the best-track position while plus
sign (+) represents relative operational position. Data
have been fitted to a bivariate normal distribution.

The errors plotted on Fig. 3 contain very little bias, are nearly cir-
cularly distributed (though not circular normal) and the components
are not significantly correlated. The average vector displacement
error was determined to be 26.8 nmi.   If the position errors are fur-
ther subdivided into two subsets of data, one set within 500 nmi of
the continental United States and another set beyond that distance,
the average position errors are about 22 and 30 nmi, respectively. The

smaller errors closer to the U.S. mainland probably reflect the condi-
tion of better satellite gridding, increased aircraft surveillance and
radar coverage when storms are approaching the coast. This is consis-
tent with the findings of Hope (1971) who showed (see Fig. 4) that
aircraft position error varies inversely as the number of aircraft fixes
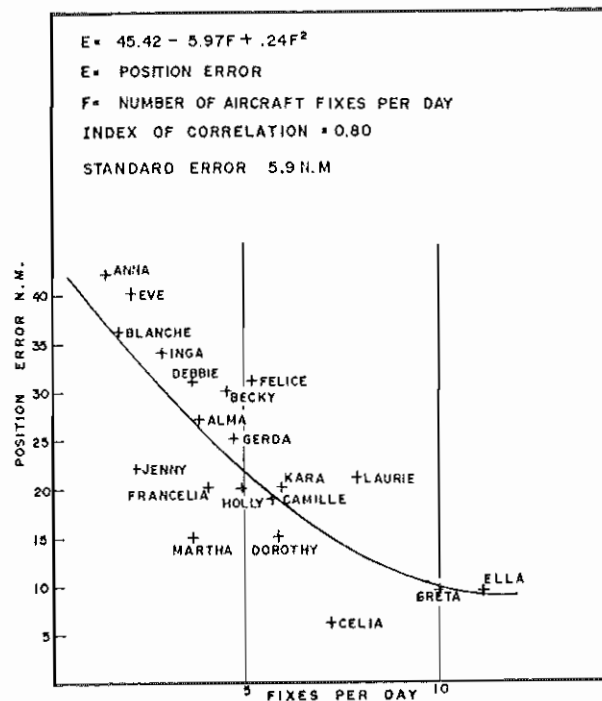per day.

Fig. 4.   Position error vs. average number of aircraft "fixes" per
          day based on data from 1971 and 1972 hurricane season.
          (From Hope, 1973)

        b.   Initial motion errors. Successive estimates of storm position
enables the forecaster to estimate average motion of a storm over the
past 12 or 24 hours. This past motion together with the latest avail-
able "fix" on the storm position further enables the forecaster to
estimate current storm motion. As pointed out in section 2, it is
impossible to specify the exact initial motion of a storm since this
implies a knowledge of the future storm track. The exact specifica-
tion of initial storm motion must therefore be considered to be a
limiting condition.

Fig. 5 is a plot of the 465 initial motion errors. As was done in
Fig. 3, the data were fitted to a bivariate normal distribution. This

theoretical fit to the observed data is better than the fit to the
position errors but, as shown by Crutcher and Elms (1973), the accept-
ance of the distribution is still somewhat marginal.
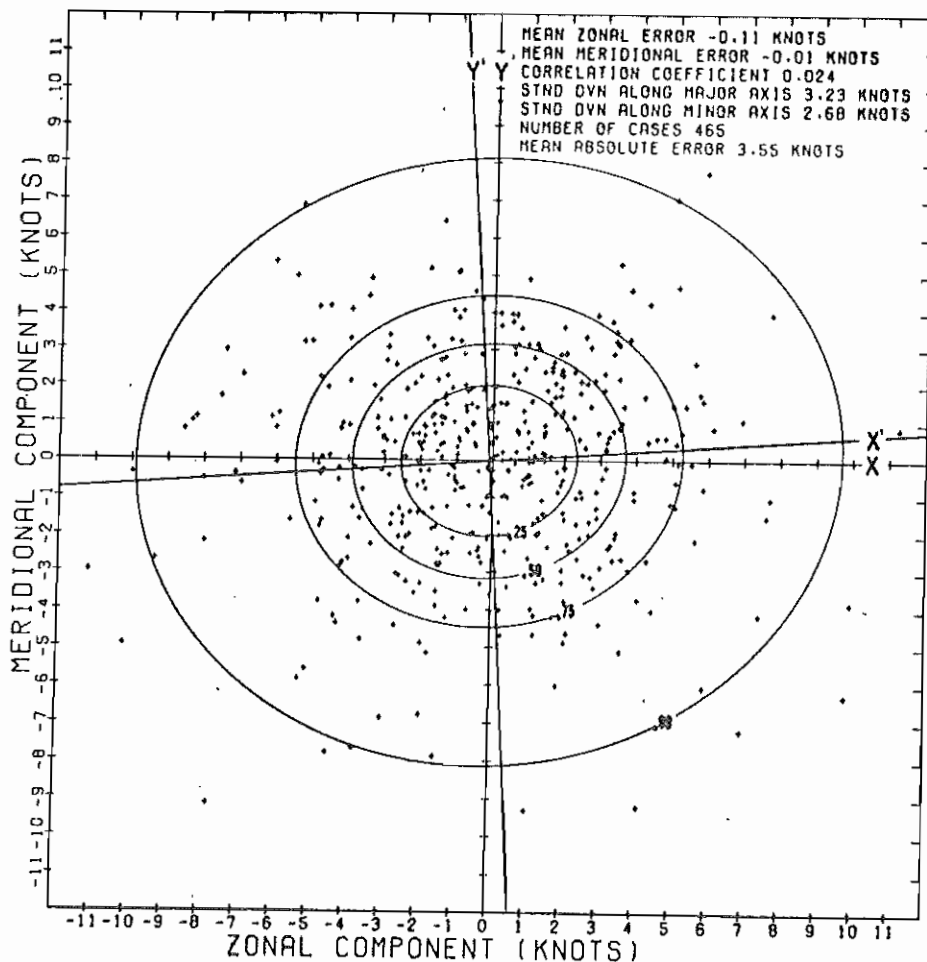

Fig. 5.   Tropical cyclone initial motion errors 1968 through 1972.
          Plus sign (+) represents end point of vector drawn from best-
          track initial motion vector (origin) to operational estimate
          of initial motion vector. Data have been fitted to a
          bivariate normal distribution (see text).

As was the case with the position errors, the data show practically no
bias, are nearly circular and the components show practically no correla-
tion. An assumption of circular normalcy could be made without serious
error. The average magnitude of the vector error was found to be 3.5
knots. Thus, if a storm forecast were to be based only on straight-
line extrapolation, the best track forecast would diverge from the
operational forecast 3.5 nmi, for each hour of the forecast period.

4. EFFECT OF THE DATA UNCERTAINTIES ON SYSTEM PERFORMANCE

It has long been known that errors of the type depicted in Figs. 3 and 5 have detrimental effects on the performance of the statistical models. In order to determine the specific impact of these errors, the 1973 forecasts for CLIPER, NHC72 and NHC73 were re-run using the best-track determined initial input data in lieu of the original operational data. Two selected forecasts illustrate the extreme sensitivity of these models to the initial input data.

Fig. 6 shows the CLIPER forecast on storm Brenda. In this case, since the storm was over land, the initial position was correctly estimated to be near the City of Merida. Uncertainties in the exact center of the storm over the previous 12 hours, together with the forecaster's knowledge that a southwesterly motion is highly unlikely in this area for this time of the year, led to an initial motion vector with an insufficient southerly component. However, even this slight difference was sufficient to produce the widely different forecast tracks shown in Fig. 6.
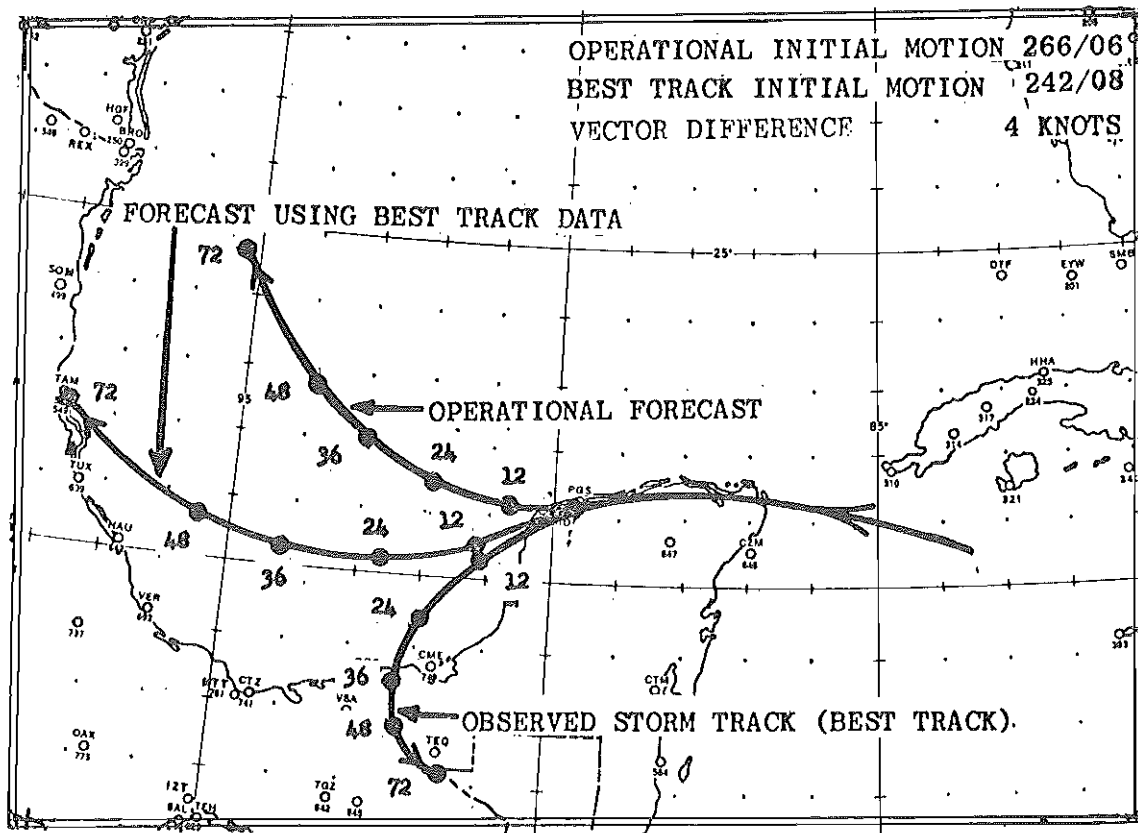

Fig. 6. CLIPER forecast on Storm Brenda, 08/20/1973/0000GMT

Another example, this time on the NHC72 model, is shown in Fig. 7.
This forecast was on a storm far removed from the United States main-
land. In this instance, little information on the storm had been
received over the past 12 hours and the forecaster's position estimate
was too far to the north-northeast. Consistent with the position
error, the initial motion error had too much northerly component. The
serious effect on the performance of the model is shown in the result-
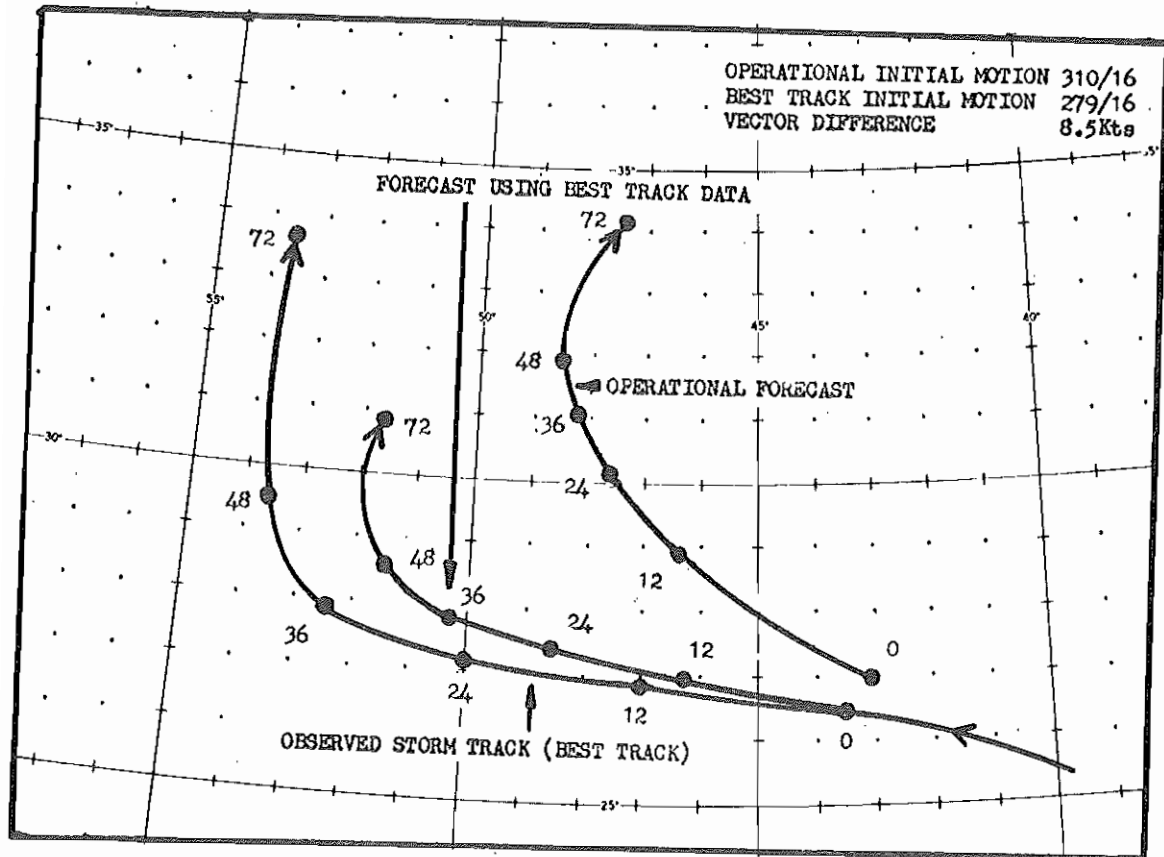ant forecast track.

Fig. 7. NHC72 forecast on Storm Ellen, 09/18/1973/1200GMT

The 1973 seasonal summary of these errors for all available cases for
the CLIPER, NHC72 and NHC73 models is given in Table 2. Also given
in the table are the percentage improvement of the best-track forecasts
over the operational forecasts. These percentages together with the
operational forecasts are shown graphically in Figs. 8, 9 and 10 with
subjectively drawn curves connecting the data points. The degradation
in the performance of the various systems is closely allied to that
which one might expect from data presented in Fig. 3. For the NHC72

	12 hour	24 hour	36 hour	48 hour	72 hour
CLIPER					
Number of Cases	95	83	69	55	27
Best-Track Fcst	39	99	171	247	333
Operational Fcst	57	128	210	295	381
Percentage Iprvmt	45	29	23	20	15
NHC72					
Number of Cases	95	83	69	55	27
Best-Track Fcst	40	96	163	247	350
Operational Fcst	54	108	179	263	353
Percentage Iprvmt	34	13	10	7	1
NHC73					
Number of Cases	43	37	30	25	12
Best-Track Fcst	33	71	133	211	398
Operational Fcst	45	87	149	227	398
Percentage Iprvmt	37	22	12	7	0

Table 2. Displacement errors (nmi) using best-track and operational input data on specified statistical prediction systems for the 1973 hurricane season

and NHC73 forecasts, for example, the influence of synoptic data is such that it becomes the predominant predictor in the latter forecast periods and the performance of these two models at 72 hours is virtually independent of the initial data uncertainties. For the CLIPER system, however, the stabilizing influence of the synoptic data is not available and the effects of the initial data uncertainties are evident even at the 72 hour forecast period.

5. DISCUSSION AND SUMMARY

It has been shown that better estimates of initial storm position and, in particular, initial storm motion would result in substantial reduction in short-range forecast errors associated with statistical tropical cyclone prediction models. A discussion on possible ways to achieve such improvements, if indeed, such improvements are even possible, is beyond the scope of the present paper. It seems obvious, however, that since persistence is such an important factor in reducing the variance of tropical cyclone motion every effort should be made to provide a more conservative estimate of storm motion than is currently available.
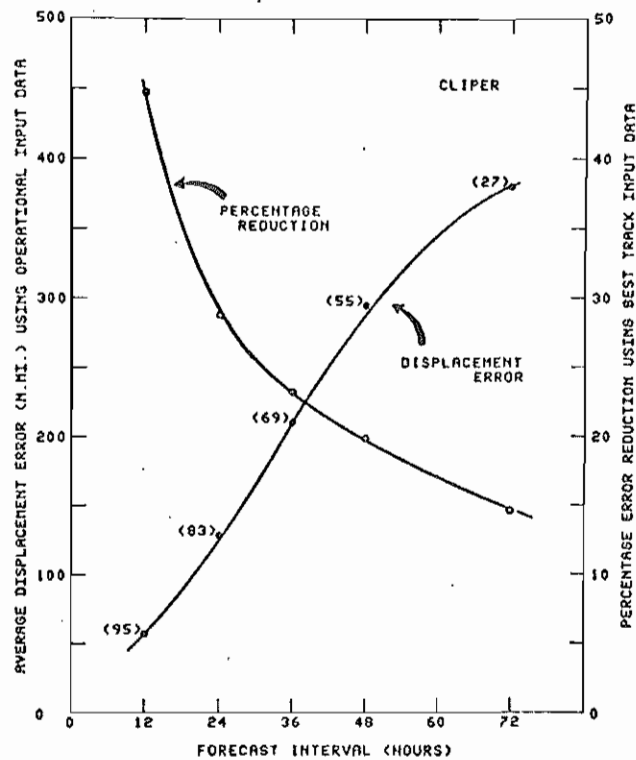
Fig. 8. Observed displacement errors for CLIPER forecast model for Atlantic 1973 hurricane season (left scale) and percentage reduction in these errors (right scale) by using best-track data. Numbers in parenthesis give number of cases.
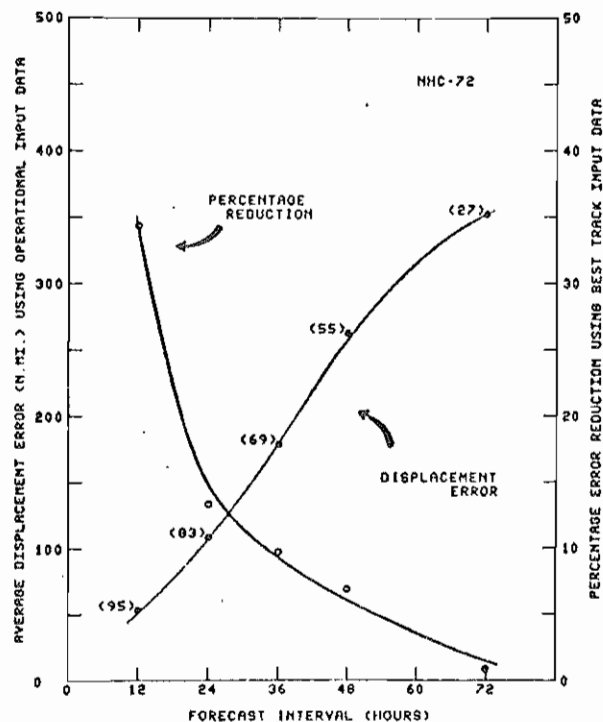

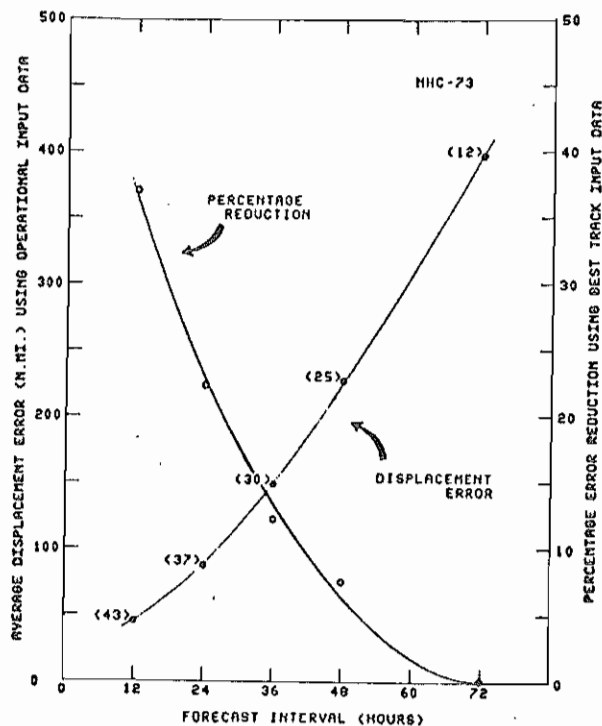Fig. 9. Same as Fig. 8 except for NHC72 prediction model.

Fig. 10. Same as Fig. 8 except for NHC73 prediction model.

The data shown in Figs. 3 and 5, recently brought up to date through the 1974 hurricane season, disclose only a slight trend towards a reduction of initial positioning and motion errors over the seven year period 1968 through 1974. It does not seem likely that significant improvements will be forthcoming over the next several hurricane seasons. It seems desirable then, that the statistical forecasting systems should be modified so as to weight persistence and climatology commensurate with the ability to provide such data in an operational environment.

Such modifications could be accomplished in one of two ways. One method would be to use the error data contained in Figs. 3 and 5 as the basis for a Monte Carlo simulation of the forecast errors. These randomly selected errors would then be appended to the best track to simulate operational conditions. A re-screening of the statistical systems would then be required using the "contaminated" data as predictors in lieu of the best-track data. Although such a procedure would assure that the statistical models are "tuned" to the data, a serious shortcoming would be the failure of the system to respond to any improvements in the ability to better estimate initial conditions. The entire procedure is analogous to the use of Model Output Statistics (MOS) in lieu of "perfect-prog" data in the development of statistical prediction systems (see Klein and Glahn, 1974).

Another method would be to use the same prediction equations and base the weighting factors used to combine subsystems (see Fig. 1) on a few years of operational data rather than on the dependent best-track data as is now done. This method has particular merit in that alteration of the weighting factors is a relatively simple procedure and could be done on an annual basis thus assuring accord between the forecaster's ability to provide initial position and motion data and the system's usage of such data.

It is considered likely that future statistical tropical cyclone prediction systems developed at NHC will use one of these approaches. Both methods should provide a better means of obtaining the maximum benefit from persistence and climatology.

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